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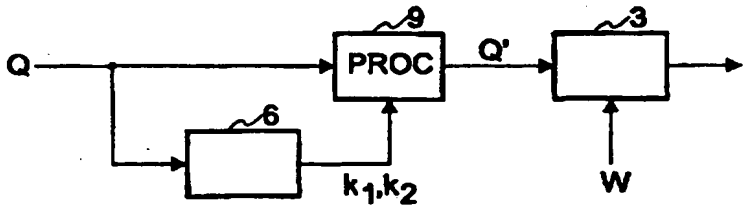
(54) Title: WATERMARK DETECTION



(57) Abstract: Most watermarking schemes are not resistant to geometric distortions of a watermarked image, because such manipulations destroy the correlation between the original watermark and the watermark in the manipulated image. A method and arrangement are disclosed that restore the correlation. To this end, a suspect image (Q) is analyzed (6) for the presence of a repeated data pattern. If such a pattern is found, it is concluded that the image has been watermarked by "tiling" a small-sized watermark pattern over the extent of the image. The actual detection of whether the watermark is a given watermark W is subsequently performed by determining the periodicity of the pattern found in the suspect image, and processing (9) the suspect image so as to match the periodicity of the processed image with the given periodicity of the watermark to be detected. If the suspect image indeed includes the given watermark W, the geometric manipulation is thereby undone and a conventional watermark detector (3) will signify this accordingly. If a combination of operations can generate the same periodicity, the detection step will include the set of possible combinations.

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Watermark detection.

FIELD OF THE INVENTION

The invention relates to a method and apparatus for detecting a watermark embedded in a suspect image.

BACKGROUND OF THE INVENTION

Watermarking is a technique to certify the ownership of images or video. Usually, the watermark is embedded by adding a specific low-amplitude noisy pattern to the image. The noisy pattern represents the watermark. Whether or not a suspect image has an embedded given watermark is detected at the receiver end by computing the correlation of the suspect image with an applied version of said watermark, and comparing the correlation with a threshold. If the correlation is larger than the threshold, the applied watermark is said to be present, otherwise it is said to be absent.

Applicant's previously filed International Patent Application IB99/00358 (PHN 17.316) discloses an arrangement for detecting a watermark that is embedded by repeating a small-sized basic watermark pattern over the extent of the image. Such a "tiling" operation allows the watermark detection process to search the watermark over a relatively small space and improves the reliability of detection.

It is known that most watermarking techniques are not resistant to geometric distortions of the image. Manipulations such as translation, scaling, rotation, or stretching destroy the correlation between the manipulated image and the applied watermark. The above-mentioned prior-art watermark detector is resistant to translation but lacks the ability of detecting the watermark if the image has been scaled, rotated or stretched.

OBJECT AND SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved watermark detection method and apparatus.

To this end, the method of detecting a watermark in a suspect image comprises the steps of detecting whether said suspect image includes a periodically repeated embedded data pattern, and concluding that said periodically repeated data pattern represents an

embedded watermark. The invention is based on the recognition that operations such as scaling, rotating and stretching change but do not destroy the periodicity of a watermark if said watermark is embedded by means of the above-mentioned "tiling" operation. Accordingly, the mere presence of a periodically repeated data pattern in the suspect image signifies that the image has been watermarked.

Detection as to whether the embedded watermark is a specific given watermark is achieved by processing the suspect image or the given watermark is such a way that the original correlation is restored. This is achieved in an embodiment of the method which comprises the steps of determining the periodicity of said data pattern, applying a given watermark having a given periodicity, processing the suspect image and/or the given watermark so as to match the periodicity of the data pattern in the processed suspect image with the periodicity of the processed given watermark, and detecting whether the data pattern in the processed suspect image corresponds to the processed given watermark. The aim of the step of processing the suspect image is to undo the manipulation (scaling, rotation, stretching) which the suspect image has undergone after it is watermarked.

Unites States Patent US-A-5,636,292 discloses the step of adding a separate calibration signal (e.g. a sine wave with a specified frequency) to the image. When the image is scaled or rotated, the frequency of the sine wave changes, which results in a peak displacement in the image's frequency spectrum. The invention differs from this prior art in that the periodic watermark pattern itself provides the calibration parameters.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a prior-art watermark embedder.

Fig. 2 shows a watermarked image to illustrate the operation of the watermark embedder which is shown in Fig. 1.

Fig. 3 shows a prior-art watermark detector.

Fig. 4 shows schematically an operation carried out by the watermark detector which is shown in Fig. 4.

Figs. 5A-5C show the effects of scaling, rotation and shearing, respectively, on a watermarked image.

Fig. 6 shows a watermark detector in accordance with the invention.

Figs. 7A-7C show correlation patterns to illustrate the operation of the watermark detector which is shown in Fig. 6.

Figs. 8-10 show further embodiments of a watermark detector in accordance with the invention.

Fig. 11 shows various types of processing applied to a given watermark to illustrate the operation of the watermark detector which is shown in Fig. 10.

Fig. 12 shows the effect of a combination of manipulations applied to a watermarked image.

DESCRIPTION OF EMBODIMENTS

In order to provide background information, a prior-art watermark embedder and a prior-art watermark detector are described first. Fig. 1 shows a practical embodiment of a prior-art watermark embedder. The embedder comprises an image source **11**, which generates an image P, and an adder **12** which adds a given watermark W' to the image P. The watermark W' is a noise pattern having the same size as the image, e.g. N_1 pixels horizontally and N_2 pixels vertically (for example, 720×576 for PAL-TV). It is generated by repeating, and if necessary truncating, smaller basic watermark patterns or "tiles" W over the extent of the image. This tiling operation, which is carried out by a tiling circuit **13**, is illustrated in Fig. 2. The basic patterns W have a fixed size $M_1 \times M_2$, for example, 128×128 pixels.

Fig. 3 shows a practical embodiment of a prior-art watermark detector. The detector receives possibly watermarked images Q. The image (or a number of accumulated video frames) is partitioned into blocks having the size $M_1 \times M_2$ of the basic watermark pattern W to be detected (here, 128×128). The blocks are then stacked in a buffer q of size $M_1 \times M_2$ as illustrated in Fig. 4. These operations are carried out by a folding and buffer circuit **31**.

To detect whether or not the buffer q includes the given watermark pattern W, the buffer contents and said watermark pattern W are subjected to correlation. Computing the correlation of a suspect information signal q with a watermark pattern w comprises computing the inner product $d=\langle q,w \rangle$ of the information signal values and the corresponding values of the watermark pattern. For the two-dimensional $M_1 \times M_2$ image block $q=\{q_{ij}\}$ and watermark pattern $W=\{w_{ij}\}$, the inner product can be written in mathematical notation as:

$$d = \frac{1}{M_1 M_2} \sum_{i=1}^{M_1} \sum_{j=1}^{M_2} q_{ij} w_{ij} .$$

As the suspect image Q may have undergone manipulations such as translation or cropping prior to the watermark detection, the detector does not know the spatial location of the watermark pattern W with respect to the boundaries of image block q. A multiple of correlations d_k must therefore be calculated for all possible shift vectors k (k_x pixels horizontally and k_y pixels vertically):

$$d_k = \frac{1}{M_1 M_2} \sum_{i=1}^{M_1} \sum_{j=1}^{M_2} q_{ij} w_{i+k_x, j+k_y}$$

Said correlation values d_k can be simultaneously computed using the (Fast) Fourier Transform. Both the contents of buffer q and the basic watermark pattern W are subjected to a Fast Fourier Transform (FFT) in transform circuits **32** and **33**, respectively. These operations yield:

$$\hat{q} = \mathrm{FFT}(q) \text{ and}$$

$$\hat{w} = \mathrm{FFT}(w),$$

where $\hat{q}$ and $\hat{w}$ are sets of complex numbers.

Computing the correlation is similar to computing the convolution of q and the conjugate of W. In the transform domain, this corresponds to:

$$\hat{d} = \hat{q} \otimes \mathrm{conj}(\hat{w})$$

where the symbol $\otimes$ denotes pointwise multiplication and conj() denotes inverting the sign of the imaginary part of the argument. In Fig. 3, the conjugation of $\hat{w}$ is carried out by a conjugation circuit **34**, and the pointwise multiplication is carried out by a multiplier **35**. The set of correlation values $d=\{d_k\}$ is now obtained by inverse Fourier transforming the result of said multiplication:

$$d = \mathrm{IFFT}(\hat{d})$$

which is carried out by an inverse FFT circuit **36**. The correlation values d_k are subsequently compared with a given threshold in a threshold circuit **37**. The watermark pattern W is detected to be present if one of the correlation values has a significant peak, i.e. larger than the threshold.

The prior-art detection method lacks performance if the suspect image has been subjected to manipulations that affect the size and/or geometric form of the embedded watermark pattern. Examples of such manipulations are scaling, rotation and stretching (or shearing). Such manipulations, which have the property that straight lines remain straight, parallel lines remain parallel, while for non-parallel lines the angle may change, are often referred to as affine transforms. Figs. 5A-5C show the effects of scaling, rotation and shearing, respectively, on the watermarked image shown in Fig. 2. similar as in Fig. 2, the basic

watermark patterns are symbolically shown as a clearly visible W. However, each W is a low-amplitude, imperceptible, noisy pattern in practice. It will be appreciated that the correlation between the suspect images shown in Figs. 5A-5C and the originally embedded watermark (see Fig. 2) has largely been destroyed.

Fig. 6 shows schematically a watermark detector in accordance with the invention. The detector calculates the autocorrelation of the suspect image and determines whether said correlations exhibit a periodic pattern. The embodiment of the watermark detector shown in Fig. 6 calculates the autocorrelation of the suspect image. More in particular, the detector calculates the correlations

$$d_k = \frac{1}{N_1 N_2} \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} q_{ij} q_{i+k_x, j+k_y} ,$$

between suspect image Q and a shifted version of the same image for all possible shift vectors k (k_x pixels horizontally and k_y pixels vertically). As already described above with reference to Fig. 3, the required calculations can be advantageously carried out by using the (Fast) Fourier Transform. Accordingly, the detector comprises an FFT circuit **61**, a conjugation circuit **62**, a multiplier **63** for pointwise multiplying the transformed image and the conjugated version thereof, and an inverse FFT circuit **64**.

The output of the inverse FFT circuit **64** is an $N_1 \times N_2$ matrix of correlation values d_k. The center (0,0) of this matrix represents the correlation for $k_x=0$, $k_y=0$. Said value is extremely large because it represents the correlation between the suspect image and itself. The correlation quickly declines as the shift is larger. However, if the image includes a repeated watermark pattern, the matrix has local peaks at the coordinates for which the watermark patterns in the image and its shifted version coincide. Figs. 7A-7C show such peak patterns for the manipulated images that are shown in Figs. 5A-5C, respectively. For completeness, it is be noted that the matrix may also include peaks for shifts $|k_x|>N_1/2$ and $|k_y|>N_2/2$ due to aliasing. These peaks generally have a low value and are not shown in Figs. 7A-7C.

A peak detection and analysis circuit **65** detects the peaks and analyzes whether the peak pattern exhibits a repetitive pattern. To this end, the circuit determines whether at least a subset of the peaks constitutes a regular pattern. Such analysis algorithms are known in the art. For example, there are mathematical algorithms that search basic vectors with which the periodical peak pattern can be reconstructed through linear combination. Examples of basic vectors thus found are denoted k_1 and k_2 in Figs. 7A-7C. If a repetitive peak pattern is found by the mathematical analysis, the circuit **65** outputs a detection signal D to indicate that

the suspect image is most likely an image that has been watermarked by means of a tiling operation as explained above. The circuit **65** also outputs the basic vectors k_1 and k_2 for use by further processing circuits as will be described below.

Another embodiment of the watermark detector is shown in Fig. 8. This detector calculates the correlation between different image regions rather than the autocorrelation. The detector comprises an image splitting circuit **81** which divides the image into two regions, for example a left half Q_L and a right half Q_R. A correlation circuit comprising a first FFT circuit **82**, a second FFT circuit **83**, a conjugation circuit **84**, a multiplier **85** and an IFFT circuit **86** calculates the correlation between the two half images in a manner as described above. It generates a peak pattern which has now half the image size. The peak pattern is applied to a peak detection and analysis circuit **87** which operates in a similar manner as peak detection and analysis circuit **65** in Fig. 6. The need for two FFT circuits (**82, 83**) in Fig. 8 compared with the single FFT circuit (**61**) in Fig. 6 is largely compensated by reduction of the computational complexity. It will be appreciated that the computational complexity can be further reduced by dividing the image into even more regions.

The watermark detectors shown in Figs. 6 and 8 do not provide information as to whether the embedded watermark is a specific given watermark. A watermark detector which does detect the presence of a given watermark in a possibly manipulated suspect image is shown in Fig. 9. The watermark detector comprises a conventional watermark detection device **3** as described before with reference to Fig. 3. In accordance with the invention, the suspect image Q is now processed by an image processing device **9** before being applied to the conventional detector **3**. The task of image processor **9** is to undo the manipulations that the image Q has undergone after the watermark was embedded. To this end, the image processor **9** receives parameters representative of said manipulations from an analysis device **6**. The analysis device is a device as described above with reference to Fig. 6 or Fig. 8. The basic vectors k_1 and k_2 found by the device (see Figs. 7A-7C) are examples of parameters that are indicative of the periodicity of the basic watermark pattern in image Q. The image processor **9** is arranged to manipulate (scale, rotate, shear or combinations thereof) the image Q in response to said parameters so that the processed image Q' exhibits a given periodicity. More particularly, the suspect image is processed so that the two basic vectors in the processed image are orthogonal with respective lengths M_1 and M_2 (here 128). Algorithms with which this can be achieved are generally known in the field of image processing.

The same result is achieved when the watermark to be detected is subjected to the same manipulations as the suspect image, and the presence of said manipulated watermark pattern in the suspect image is subsequently detected. An embodiment of such a watermark detector is shown in Fig. 10. The manipulation parameters k_1 and k_2 found by analysis device **6** are now applied to a processing circuit **10** which carries out the same manipulations to the basic watermark pattern W. The 128×128 watermark pattern W is thus transformed into a version W" which corresponds to the pattern in the suspect image. This is illustrated in Fig. 11 which shows a scaled watermark pattern **11a**, a rotated watermark pattern **11b** and a sheared watermark pattern **11c** corresponding to the image manipulations that are shown in Figs. 5A-5C, respectively.

A potential problem of the watermark detector shown in Figs. 9 and 10 is that the processing operation to be carried out by the image processor **9** or **10** is not unambiguously defined by the basic vectors k_1 and k_2. As an example thereof, Fig. 12A shows the effect of rotating an image through 90° and subsequently shearing the result. The peak pattern found by the analysis device **6**, and thus the periodicity, is exactly the same as the periodicity of an image which has been sheared only (cf. Fig. 5C). If the image processor merely undoes the shearing operation, the watermark will not be detected. Fortunately, the number of (combinations of) manipulations that lead to the same peak pattern is limited, and many of them are not used in practice. In view thereof, the processing circuit (**9** in Fig. 9, **10** in Fig. 10) in a preferred embodiment of the watermark detector executes a plurality of appropriate candidate inverse manipulations, and the watermark detector **3** detects the presence of the watermark on the basis of the one which gives the highest correlation. Such an embodiment can easily be designed by a skilled person in view of the foregoing description and will therefore not be described in more detail.

The invention is summarized as follows. Most watermarking schemes are not resistant to geometric distortions of a watermarked image, because such manipulations destroy the correlation between the original watermark and the watermark in the manipulated image. A method and arrangement are disclosed that restore the correlation. To this end, a suspect image (Q) is analyzed (6) for the presence of a repeated data pattern. If such a pattern is found, it is concluded that the image has been watermarked by "tiling" a small-sized watermark pattern over the extent of the image. The actual detection of whether the watermark is a given watermark W is subsequently performed by determining the periodicity of the pattern found in the suspect image, and processing (9) the suspect image so as to match the periodicity of the processed image with the given periodicity of the watermark to be detected. If the suspect

image indeed includes the given watermark W, the geometric manipulation is thereby undone and a conventional watermark detector (3) will signify this accordingly. If a combination of operations can generate the same periodicity, the detection step will include the set of possible combinations.

CLAIMS:

1. A method of detecting a watermark (W) in a suspect image (Q), comprising the steps of detecting (61-64) whether said suspect image includes a periodically repeated embedded data pattern, and concluding (65) that said periodically repeated data pattern represents an embedded watermark.

2. A method as claimed in claim 1, further comprising the steps of
- determining (6) the periodicity of said data pattern,
- applying a given watermark (W) having a given periodicity,
- processing (9;10) the suspect image and/or the given watermark so as to match the periodicity of the data pattern in the processed suspect image with the periodicity of the processed given watermark, and
- detecting (3) whether the data pattern in the processed suspect image corresponds to the processed given watermark.

3. A method as claimed in claim 2, wherein the step of processing (9;10) the suspect image and/or the given watermark comprises subjecting the suspect image and/or the given watermark to an affine transform operation.

4. A method as claimed in claim 2 or 3, wherein the step of processing (9;10) the suspect image and/or the given watermark is repeated for a finite set of predetermined processing operations.

5. An arrangement for detecting a watermark (W) in a suspect image (Q), comprising means for detecting (61-64) whether said suspect image includes a periodically repeated embedded data pattern, and means for concluding (65) that said periodically repeated data pattern represents an embedded watermark.

6. An arrangement as claimed in claim 5, further comprising:
- means for determining (6) the periodicity of said data pattern,

- means for applying a given watermark (W) having a given periodicity,
- means for processing (9;10) the suspect image and/or the given watermark so as to match the periodicity of the data pattern in the processed suspect image with the periodicity of the processed given watermark, and
- means for detecting (3) whether the data pattern in the processed suspect image corresponds to the processed given watermark.

7. An arrangement as claimed in claim 6, wherein the means for processing (9;10) the suspect image and/or the given watermark are arranged to subject the suspect image and/or the given watermark to an affine transform operation.

8. An arrangement as claimed in claim 6 or 7, wherein the means for processing (9;10) the suspect image and/or the given watermark are arranged to repeatedly perform said processing for a finite set of predetermined processing operations.

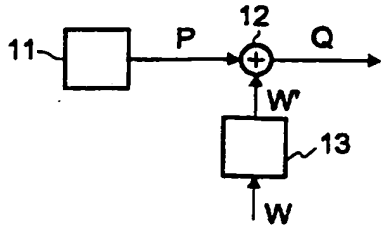

FIG.1

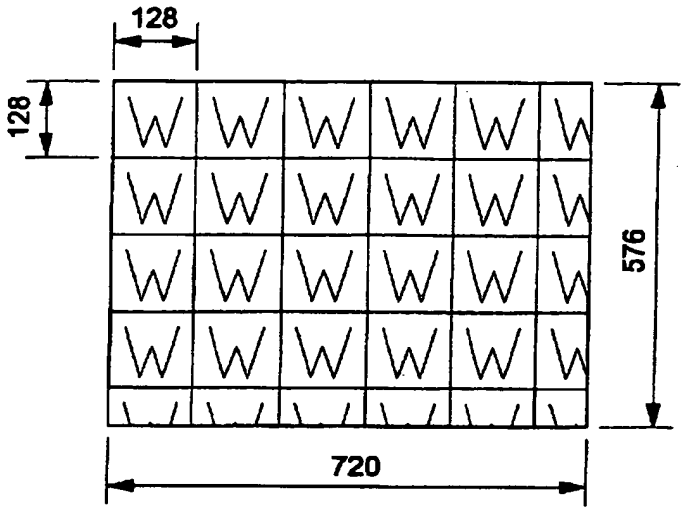

FIG.2

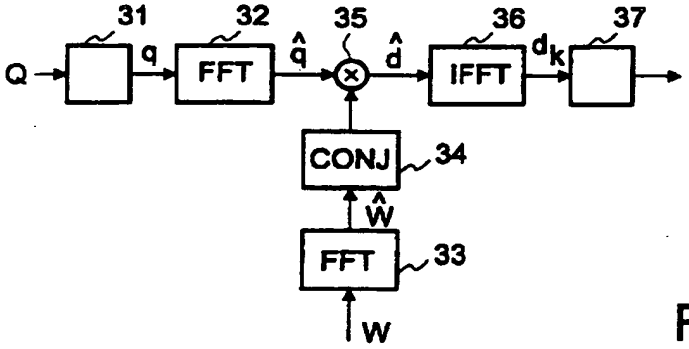

FIG.3

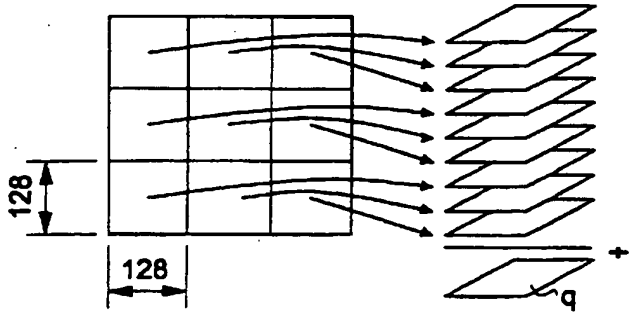

FIG.4

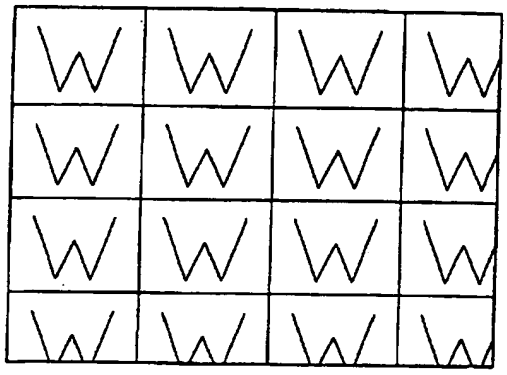

FIG.5A

FIG.5B

FIG.5C

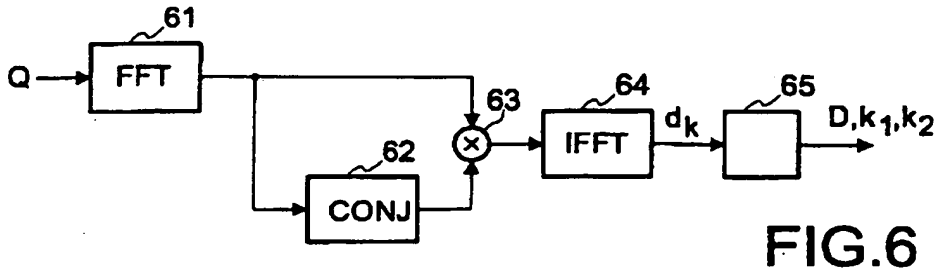

FIG.6

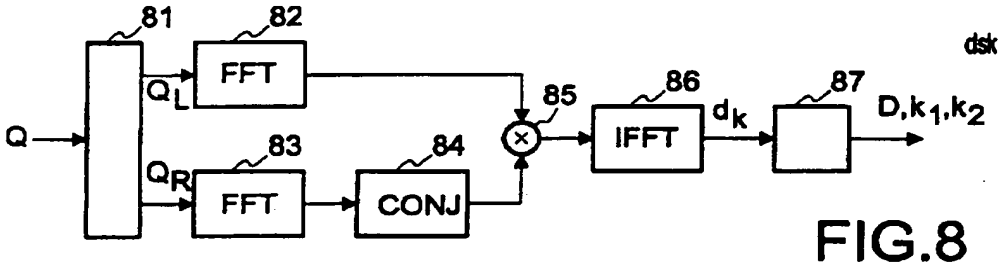

FIG.8

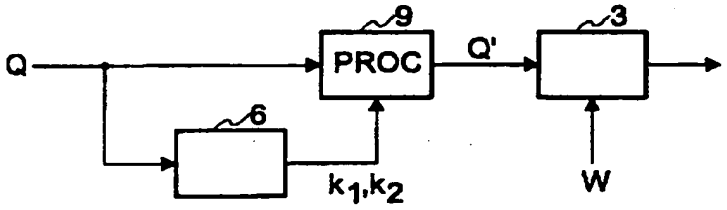

FIG.9

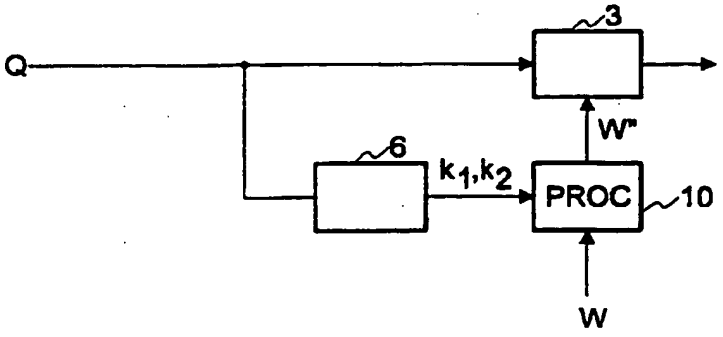

FIG.10

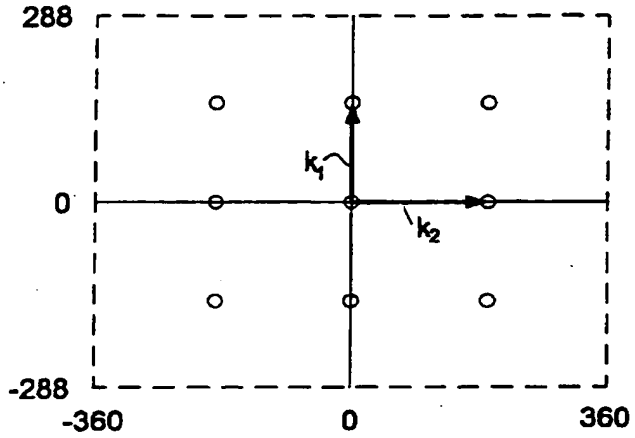

FIG.7A

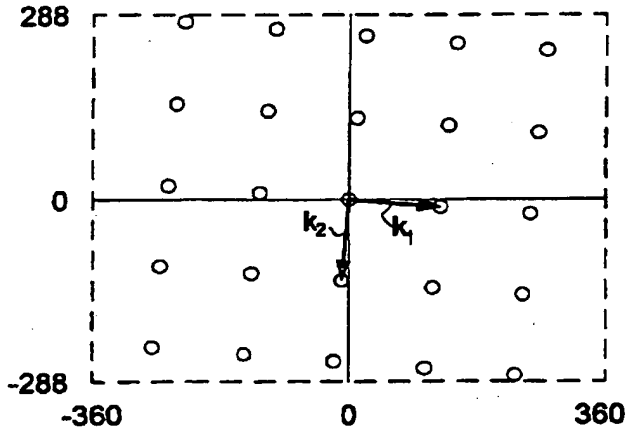

FIG.7B

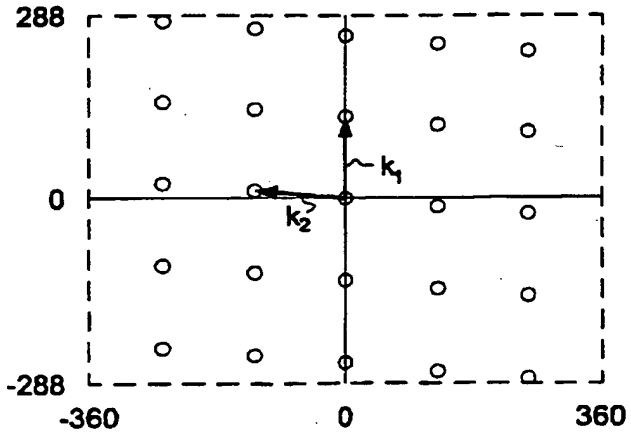

FIG.7C

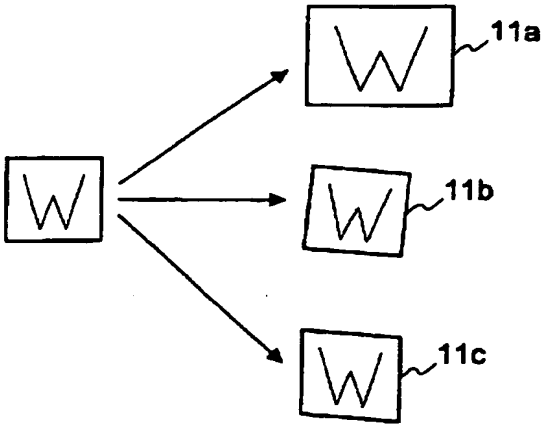

FIG.11

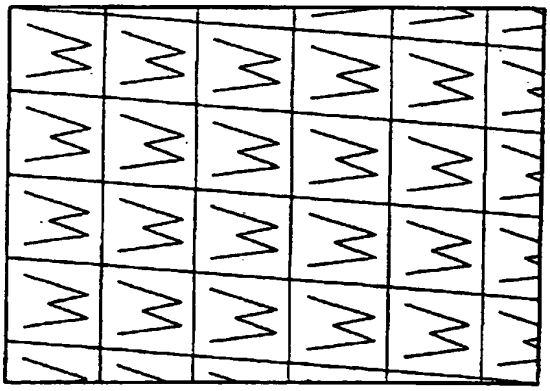

FIG.12

INTERNATIONAL SEARCH REPORT

Interna ial Application No
PCT/EP 00/09087

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 43736 A (RHOADS GEOFFREY B ;DIGIMARC CORP (US)) 20 November 1997 (1997-11-20) page 55, line 1 - line 17; figure 19	1-8
X	KALKER E.A.: "A VIDEO WATERMARKING SYSTEM FOR BROADCAST MONITORING" PROCEEDINGS OF THE SPIE, vol. 3657, 25 - 27 January 1999, pages 103-112, XP000949142 USA page 108, line 27 - line 42	1-8

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 January 2001	19/01/2001

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INTERNATIONAL SEARCH REPORT

Interr ial Application No
PCT/EP 00/09087

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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